ASSESSMENT ON EFFECT OF GEOMETRY DEFECT FOR STEEL PIPE

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ABSTRACT

The aim of this research is to study the effect of geometry defects for steel pipe subjected to stress-based criteria. The objectives for this project are to simulate the effect of corrosion geometry on steel pipeline with variable defect depth and to determine the maximum pressure on different defect geometry. This study focused on effect of width and depth defect for rectangular and groove defect. The scope of research consists of material made of API 5L grade B which involve of elastic and plastic deformation. The MSC Marc 2008r1 is used to simulate 2-D corrosion defect of pipeline which involved groove defect and rectangular defect with variables in depth and width defect. There are three different widths (0.2mm, 0.5mm and 1mm) and depths (20%, 50% and 75% from the wall thickness) are selected to be analysed. The simulation involved about 18 designs of defects. Meanwhile, half of the pipe model with the outer diameter of 60.5mm and wall thickness 4mm were simulated to analyse the defect condition. The FEA result will be compared in terms of depth defect and length of width. Besides, it also will be compared with the industry codes such as ASME B31G, Modified ASME and DNV-RP-F101. Based on analysis, the width of defect does not affect much upon the burst pressure. However, depth of corrosion defect plays an important role for the pipeline to be failed in operation. The deep defect is easily reach burst pressure compare to the shallow defect and moderately defect. On the top of that, the FEA result for burst pressure is much higher rather than industry codes. From the analysis done, the groove defect and rectangular defect tends to failed at almost the same burst pressure even the width is different. In a nutshell, the depth of corrosion defect plays an important role for burst pressure rather than width. Moreover, the different type of defect does not give huge impact on the burst pressure.

ABSTRAK

Tujuan kajian ini adalah untuk mengkaji kesan kecacatan geometri bagipaip keluli tertakluk kepada kriteria berasaskan tekanan. Objektif projek ini adalah untuk meniru kesan geometri karat pada paip keluli dengan kedalaman kecacatan berubah dan untuk menentukan tekanan maksimum kepada geometri kecacatan yang berbeza. Kajian ini memberi tumpuan kepada kesan lebar dan kedalaman kecacatan kecacatan segi empat tepat dan alur. Skop penyelidikan terdiri daripada bahan yang diperbuat daripada API 5L gred B yang melibatkan ubah bentuk anjal dan plastik. MSC Marc 2008r1 digunakan untuk mensimulasikan 2-D hakisan kecacatan saluran paip yang melibatkan kecacatan dan kecacatan alur segi empat tepat dengan pembolehubah secara mendalam dan kecacatan lebar. Terdapat tiga lebar yang berbeza (0.2mm, 0.5mm dan 1mm) dan kedalaman (20%, 50% dan 75% daripada ketebalan dinding) yang dipilih untuk dianalisis. Simulasi ini melibatkan kira-kira 18 reka bentuk kecacatan. Sementara itu, separuh daripada model paip dengan diameter luar 60.5mm dan dinding tebal 4mm adalah simulasi untuk menganalisis keadaan kecacatan itu. Hasil FEA akan dibandingkan dari segi kecacatan mendalam dan panjang lebar. Selain itu, ia juga akan dibandingkan dengan kod industri seperti ASME B31G, Modified ASME dan DNV-RP-F101. Berdasarkan analisis, lebar kecacatan tidak menjejaskan banyak kepada tekanan pecah. Walau bagaimanapun, kedalaman kecacatan karat memainkan peranan yang penting untuk saluran paip yang akan gagal dalam operasi. Kecacatan dalam mudah mencapai tekanan pecah berbanding dengan kecacatan itu cetek dan kecacatan sederhana. Di samping itu, keputusan FEA untuk tekanan pecah adalah lebih tinggi daripada kod industri. Daripada analisis yang dilakukan, kecacatan alur dan kecacatan segiempat cenderung untuk gagal di hampir tekanan pecah sama walaupun lebar adalah berbeza. Secara ringkas, kedalaman kecacatan karat memainkan peranan yang penting untuk tekanan pecah bukannya lebar. Manakala, jenis kecacatan yang berbeza tidak memberi impak yang besar terhadap tekanan pecah.

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LIST OF SYMBOLS

D	Outside diameter
D_i	Inside diameter
d	Defect depth
t	Wall thickness
L	Longitudinal corrosion defect length
P_b or P_f	Failure pressure
M	Bulging factor
R	Average pipe radius
σ_y	Yield stress
σ_f	Flow stress
σ_U	Ultimate tensile stress
Q	Corrector factor
Q_I	Oxidation charge during the fast steady oxidation period
Q_{II}	Oxidation charge during the protective oxide film recovery period
Q_{III}	Oxidation charge during the steady passive state

LIST OF ABBREVIATONS

2D	Two Dimensions
ASME	American Society for Mechanical Engineer
API	American Petroleum Institute
DNV	Det Norske Veritas
FEA	Finite Element Analysis
SMYS	Specified minimum yield strength of pipe steel
SMTS	Specified minimum tensile strength of pipe steel

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter will briefly explain about the introduction of this project task. The introduction is general information regarding the topic that will be discussed with this project. This topic will consist of background of proposed study, problem statement, objectives, scope of research and significant research. That information is important before further discuss to the analysis and study case later.

1.2 BACKGROUND OF PROPOSED STUDY

Pipelines have been used as one of the most economical, highest capacity and safety ways in transmitting oil and gas. However, a number of pipelines are still under construction all over the world which dramatically rising number of operating pipelines (Choi *et. al.*, 2003). The material properties of the pipelines yet been improved in terms of corrosion and yield strength of steel, to reduce failure during operation and decreases cost for maintenance (Amirat *et. al.*, 2006). However, the increasing of pipeline aging in operation may increase accident, causes by internal and external corrosion defects (Teixeira *et al.*, 2008). Major failures of pipeline causes by external defects are corrosion defects, gouges, foreign object scratches and pipe erection activities (Abid *et al.*, 2006). Some sections of high pressure pipeline may experience corrosion after long service histories (Ma *et al*., 2013).

The corrosion failure on the pipelines caused wall thinning on the inner and outer surface; generate stress concentration in the pipe wall. Moreover, defects due to localized corrosion have high failure risk to the pressurized pipelines (Xu and Cheng, 2012). The dimensions such as length, width and depth of corrosion defects influence the stress concentration to different extent (Length of the defect refer to the longitudinal, the width of the defect refers to the longitudinal, the width of the defect refers to the circumferential direction of the pipelines.) (Fekete and Varga, 2012).

Pipelines provide safe high-capacity transportation of natural gas and other products. Defects on the pipeline will take the operation under risk. Prediction of the burst pressure is relevance to pipeline industry (Zhou and Huang, 2012). Burst pressure is defines as limit load or failure pressure of pipe at plastic collapse, representing the maximum load bearing capacity of the pipe (Ma *et al.*, 2013).

1.3 PROBLEM STATEMENT

Recently, there are highly demand of natural gas all over the world, has simulated development of a complex pipeline network necessary to carry natural gas from extraction fields to storage sites. Accurate prediction of residual strength corroded piping system remains essential in fitness for service analyses of oil and gas transmission pipelines. To assess the integrity of corroded piping system, conventional procedure is used with axial defects generally employ simplified failure upon a plastic collapse failure mechanism incorporating the tensile properties of the pipe material (Mario *et. al*., 2009).

Failure may provide significant scatter in predictions, which lead to unnecessary repair or replacement of in service pipelines and about to increase the cost of maintenances. Central focus is to gain additional insight into effects of defect geometry and material properties in attainment local limit load for support development of stress-based burst strength criteria (*Mario et. al.*, 2009).

1.4 OBJECTIVES

For this project, main objective are listed:

a) To simulate the effect corrosion geometry on steel pipeline with variable defect depth and width.
b) To analyse the effect of maximum pressure on different defect geometry.

1.5 SCOPE OF RESEARCH

This study was focused on the effect of defect width and defect depth. The step consists of:

a) Used material made of API 5L, material grade B (API 5L L245).
b) To simulate the defect by using Software MSC Marc 2008 r1.
c) This simulation consists of elastic and plastic deformation.
d) To simulate 2D defect

1.6 SIGNIFICANT OF RESEARCH

This research is focusing on the assessment on effect of geometry defect for steel pipeline. The scope of this research is as below:

a) To simulate defect using finite element analysis.
b) To studies of different depth of defect and defect of geometry.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will briefly explain about the material used, defect over the pipeline and method in industries by solving the corrosion problem. The sources are taking from the journals, and articles and books. The literature review is helping in order to provide important information regarding previous research which related to this project. Those information are important to know before can proceed further to analysis and study later.

2.2 INTRODUCTION OF PIPELINE

Pipelines are built for transporting liquids and gases such as oil and natural gas, which commonly used in offshore and onshore industries. However, pipelines have its own time limitation before its failure in operation which being affected because of increasing of aging infrastructure. The failure of the pipelines during operation may expose accidences to be occurred. Most of the accidents occurred in natural gases and liquids pipelines are internal and external defects (Teixeira *et.al.,* 2008). The geometry defect occurred from the corrosion and material properties will affect the limit load of the pipelines before it burst. In order to reduce any potential due to undue accident caused by a lack of unawareness of integrity of the line, regular inspection of pipelines is needed.

2.3 Material in pipeline

Pipelines material is chosen by considering about their mechanical properties. High grade steel pipe is used in transporting liquid and gases over long distances in onshore and offshore (Tanguy *et.al*., 2008). There are many types of grade steel which used in pipelines such as X52, X60, X65, X70, X100, API X52 and so on. Every pipeline have its own grade, those grades will distinguish the strength of the pipe. For example the differences of chemical properties of X52 steel and X60 steel based on the table 1 below.

Table 2.1: Chemical Composition of the steels (mass %) (Tanguy *et. al*, 2008)

Steel	C	Mn	Si	P	S	Cr	Ni	V	Nb	Ti
X52	0.09	0.92	0.28	0.007	0.010	0.02	0.01	0.004	0.03	0.01
X60	0.21	1.52	0.19	0.012	0.003	0.16	0.15	0.05	0.03	0.01
X42	0.18	0.84	0.22	0.013	0.004	0.07	0.02	-	-	-

During 1950-1960, API X52 was the common material to build gas pipelines for transmission of oil and gas. The composition of the chemical composition for API X52 is shown in Table 2.2.

Table 2.2: Chemical composition of API X52 (weight %) (Adib *et.al*., 2006)

Steel	C	Mn	Si	Cr	Ni	Mo	S	Cu	Ti	Nb	Al
API X52	0.22	1.22	0.24	0.16	0.14	0.06	0.036	0.19	0.04	<0.05	0.032

Table 2.3: Chemical composition of X-65 pipeline steel (wt%). (Cheng, 2007)

Steel	C	Mn	P	Si	Cr	Ni	Cu	Nb	Al
API X65	0.11	1.50	0.013	0.26	0.006	<0.02	0.04	0.04	0.05

2.4 Type of defect in pipelines

Transmission pipelines of oil and gases have a high safety record due to a combination of good materials, design and operating practices. Major failure causing defects in gas pipeline is an external defect such as corrosion defects, gouges, foreign object scratches and pipeline erection activities (Adib *et.al*., 2007). However, external interference (known as mechanical damage) and corrosion on the surface of the pipeline causes damage and failure of the transmission pipelines. Moreover, corrosion and ground movement are two important causes resulting failure to the pipelines. Corrosion can cause defects to the pipelines due to reduction of pipeline structural integrity which increase the risk of failure. Movement of ground will produce longitudinal loads on the pipe, creating stress strain to threaten the safety of pipeline (Xu and Cheng, 2012). Dents and gouges known as mechanical damages affected on pipelines which cause adverse effects on pipeline integrity. Meanwhile, it causes local stress and also strains concentration to the pipelines (Jacob *et.al*., 2010).

2.4.1 Corrosion

Each year millions of dollars are lost because of corrosion occurred. It causes metal loss of the surface of the pipeline. The one of major reasons causing pipeline defects is corrosion. Mostly, this loss is due to corrosion of iron and steel even though there are many other metals may corrode as well (e.g. ceramics or polymers). Corrosion happens due to the electrochemical process. Usually, corrosion appears as either corrosion or localized (pitting) corrosion. There are a few types of corrosion normally occurred in pipeline, including galvanic corrosion, microbiologically induce corrosion, AC corrosion, differing soils, differential aeration and cracking (Cosham *et.al.*, 2007). Generally failures occur due to corrosion are associated with sweet (CO2) and sour (H2S) producing fluids. Corrosion defects on pipeline have a complex geometry, it been assumed as having semi-elliptical shape in some well-known codes. The radial corrosion on normal probability paper is illustrated as in Figure 2.1.

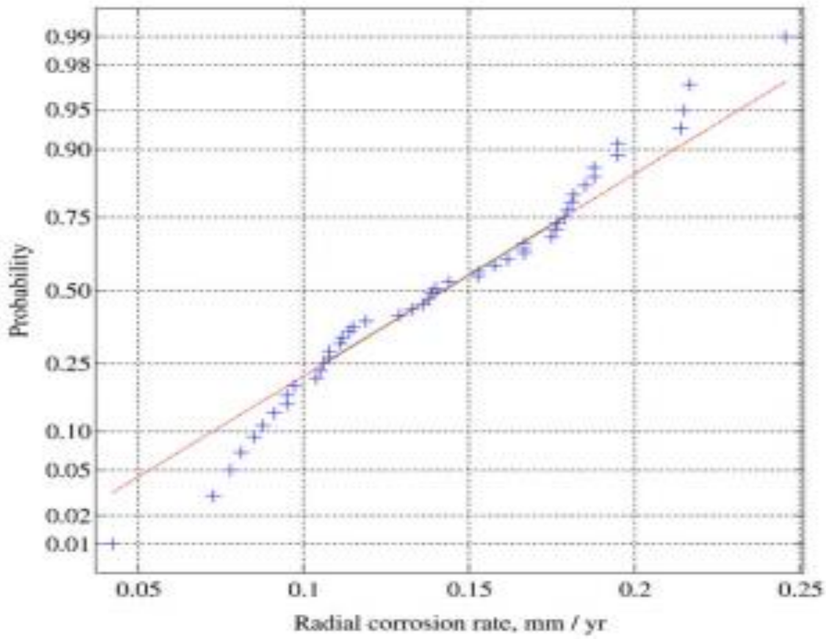

Figure 2.1: Radial corrosion on normal probability paper.

Source: Macdonald et.al.,2007

2.4.2 Gouges

A gouge result a metal loss defect which cause surface damage to pipeline due to contact with foreign object that scraped out the material out of the pipe (Macdonald and Cosham, 2005). It causes adverse effects on pipeline integrity, while it causes local stress and also strains concentration to the pipelines.

2.4.3 Dents

Dents in transmission pipelines are a permanent plastic deformation of circular cross section of the pipe. A dent is a gross distortion of the pipe cross section. Depth of dent is defined as a maximum reduction in the diameter of the pipe compared to the original diameter (Cosham and Hopkins, 2004).

According to statistical results the Office of Pipeline Safety of the U.S. Department of Transportation (DOT), from 1985 until 2003, there are about 28% incidents had been reported most of the cases related to the failures of pipeline caused by dents (Jacob *et.al*., 2010). There are several types of dents such as smooth dent, kinked dent, plain dent, unconstrained dent, and constrained dent. Smooth dent is caused by a smooth change in curvature of pipe wall. It contains a gouge is a very severe form of mechanical damage.

A smooth dent which containing gouge is lower than a burst strength of equivalent plain dent and lower than equivalent gouge in un-dented pipe (Cosham and Hopkins, 2004). The dent depths include both the local indentation and any divergence from the nominal circular cross section.

Kinked dent is a dent cause by abrupt change in curvature of pipe wall of the sharpest part of dents is less than five times the wall thickness (Cosham and Hopkins, 2004).

Plain dent is a smooth containing no wall thickness reductions such as gouge or crack or some other imperfections such as girth or seam weld (Cosham and Hopkins, 2004). It is not significantly reducing the burst strength of the pipe (Macdonald *et.al.*, 2007).

Unconstrained dent is a dent which elastically free rebound (spring back) when the indenter removed, and freely rebound as internal pressure changes (Cosham and Hopkins, 2004).

Constrained dent is a dent that not free to rebound or reround due to indenter is not removed. For example rock dent (Cosham and Hopkins, 2004). Constrained plain dents do not significantly reduce the burst strength of the pipe (Macdonald *et.al.*, 2007).

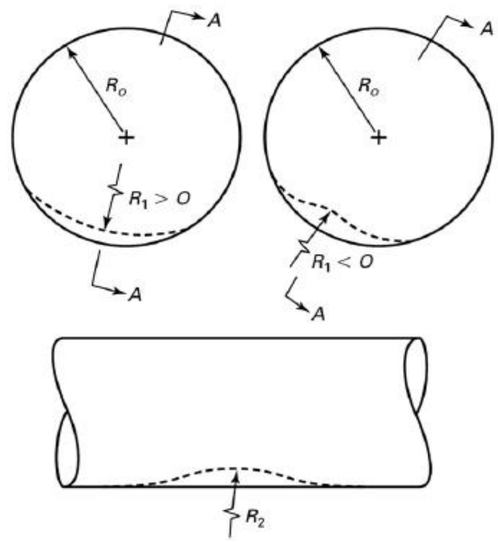

Figure 2.2: Dent geometry

Source: Jacob et.al., 2010

2.5 Codes and Standards

In pipeline industry, metal-loss corrosion is a common integrity threat. The prediction of burst pressure is most relevance to oil and gas industry (Zhou, 2012). The pressure of corroded pipes depending on the loading and scopes of the pipelines such as ASME B31G, DNV RP-F101, modified ASME B31G,PCORRC, RSTRENG, SHELL-92 and so on (Li *et al*., 2009). The semi-empirical methods based on measurement data which only consider the length and depth dimension of the simple, 2D geometrical shape are (ASME B31G), Modified ASME B31G, DNV and Advantica, which used to approximate the real corrosion failure (Fekete and Varga, 2012). Every codes are applied by considering various criteria of the test data for example ASME B31G, modified ASME B31G and RSTRENG are applicable for low, moderate, high tough steels. Meanwhile DNV-RP F101 and PCORRC are applicable for moderate to high toughness steels (Cosham et al., 2007).

	Pressure only		Combine loading	
	Length and depth	Area and depth	Pressure and bending	Area and depth
Coded method	ASME B31G			
	Modified ASME B31G			
	DNV F101	DNV F101	DNV F101	DNV F101
Other methods	RSTRENG	RSTRENG Effective	Bubenik FEM	
	Mok et. al	Leis.PCORRC	Safe-SwRi Stress model	
	Hopkins		Andrew correction factor	
	Rosenfeid		Wang-SwRi Strain model	
	Choi et al.		SINTAP	
	SINTAP			

Figure 2.3: Methods for corrosion assessment including codified and other methods

Source: Adib et.al., 2006

2.5.1 ASME B31G

American Society of Mechanical Engineers (ASME) B31G originally developed and published in 1984, it is being used widely in determine the remaining strength of corroded pipeline. For consideration of defect geometry, ASME B31G had proposes bulging factors. The flow stress based on researcher, X.Y.Xu et.al, it is not applicable for high strength steel such as x100.The researcher state that the application below is limited to evaluation of metal loss due to external or internal corrosion defect which have smooth contour with depth between 10% and 80%.

The calculation below involved the pressure failure and Folias factor of ASME B31G. Those parameters are included in List of Symbols.